

Chapter 16

Lecture Outline*

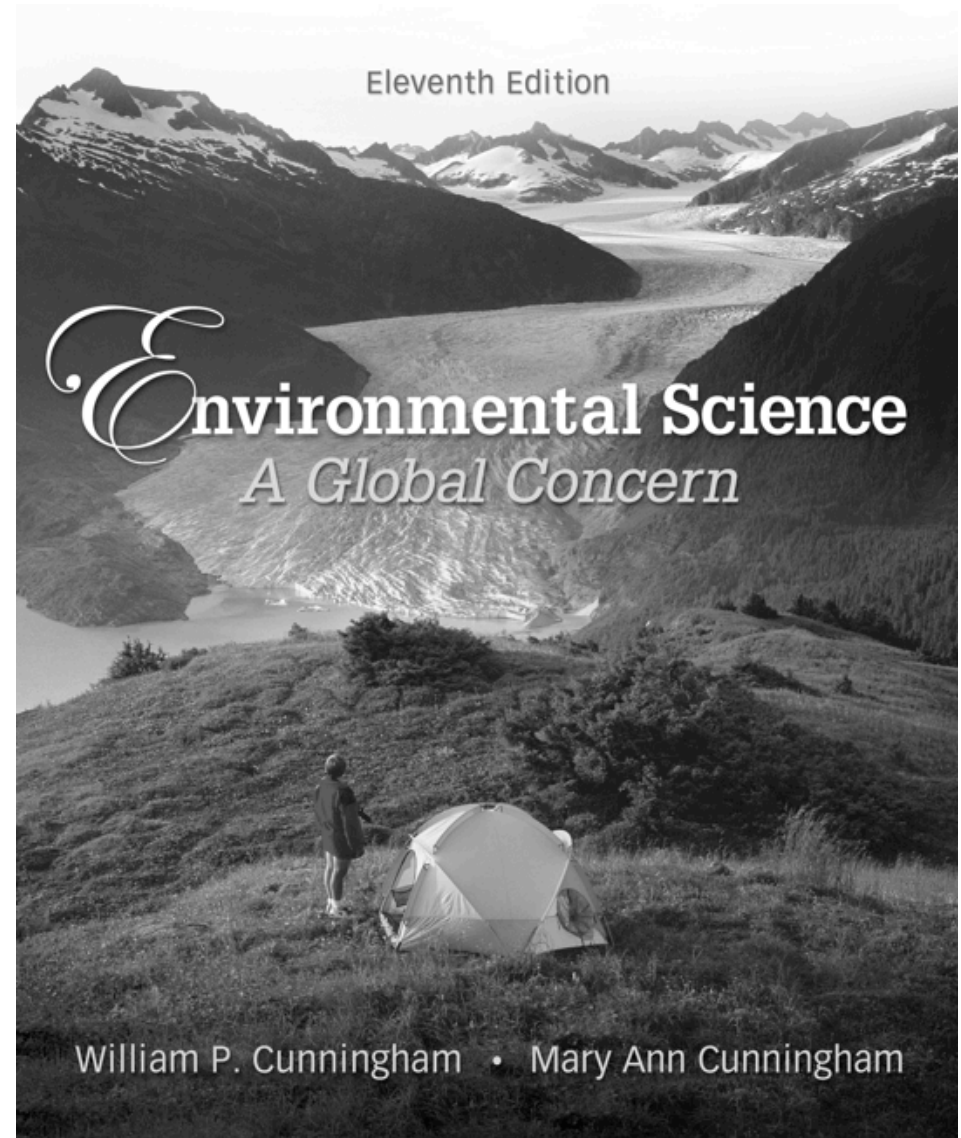
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Air Pollution

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Outline

- Natural Sources
- Human-Caused Air Pollution
 - ❖ Conventional Pollutants
 - ❖ Unconventional Pollutants
 - ❖ Indoor Air Pollution
- Climate and Topography
- Effects of Air Pollution
- Air Pollution Control
- Clean Air Legislation
- Current Conditions and Future Prospects

The Air Around Us

- Approximately 147 million metric tons of air pollution are released annually into the atmosphere in the U.S. by human activities.
 - ❖ Worldwide emissions total around 2 billion metric tons.
- Developed countries have been improving air quality, while air quality in developing world is getting worse.

Natural Sources of Air Pollution

- Volcanoes - Ash and acidic components
- Sea Spray - Sulfur
- Vegetation - Volatile organic compounds
- Pollen, spores, viruses, bacteria
- Dust storms
- Bacterial metabolism is responsible for 2/3 of methane in the air.
- Forest fires

Human-Caused Air Pollution

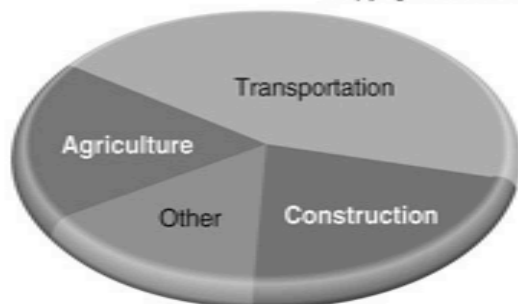
- Primary Pollutants - released directly from the source
- Secondary Pollutants - modified to a hazardous form after entering the air and mixing with other environmental components
 - ❖ Fugitive Emissions - do not go through smokestack
 - Dust from strip mining, rock crushing, building construction/destruction

Conventional Pollutants

- U.S. Clean Air Act designated seven major (conventional or criteria pollutants) for which maximum ambient air levels are mandated.
 - ❖ Sulfur Dioxide
 - ❖ Nitrogen Oxides
 - ❖ Carbon Monoxide
 - ❖ Particulates
 - ❖ Hydrocarbons
 - ❖ Photochemical Oxidants
 - ❖ Lead

Sources of Some Criteria Pollutants

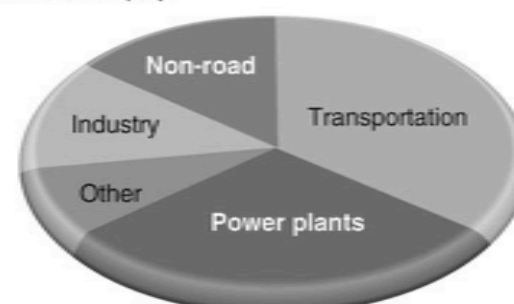
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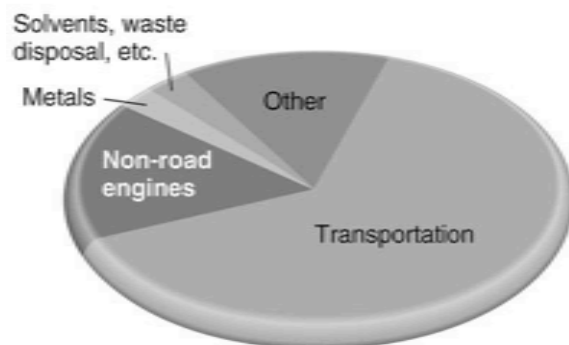
Particulate materials



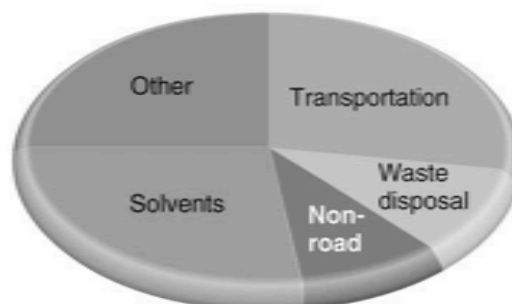
Lead



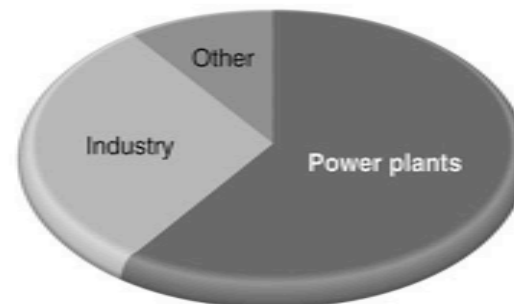
Nitrogen oxides



Carbon monoxide



Volatile Organic Compounds (VOCs)



Sulfur dioxide

Conventional Pollutants

- Sulfur Compounds
 - ❖ Natural sources of sulfur in the atmosphere include evaporation from sea spray, volcanic fumes, and organic compounds.
 - ❖ Predominant form of anthropogenic sulfur is sulfur-dioxide from fossil-fuel combustion (coal and oil) and smelting of sulfide ores.
 - Sulfur dioxide is a corrosive gas which reacts with water vapor in the air to cause acid rain.

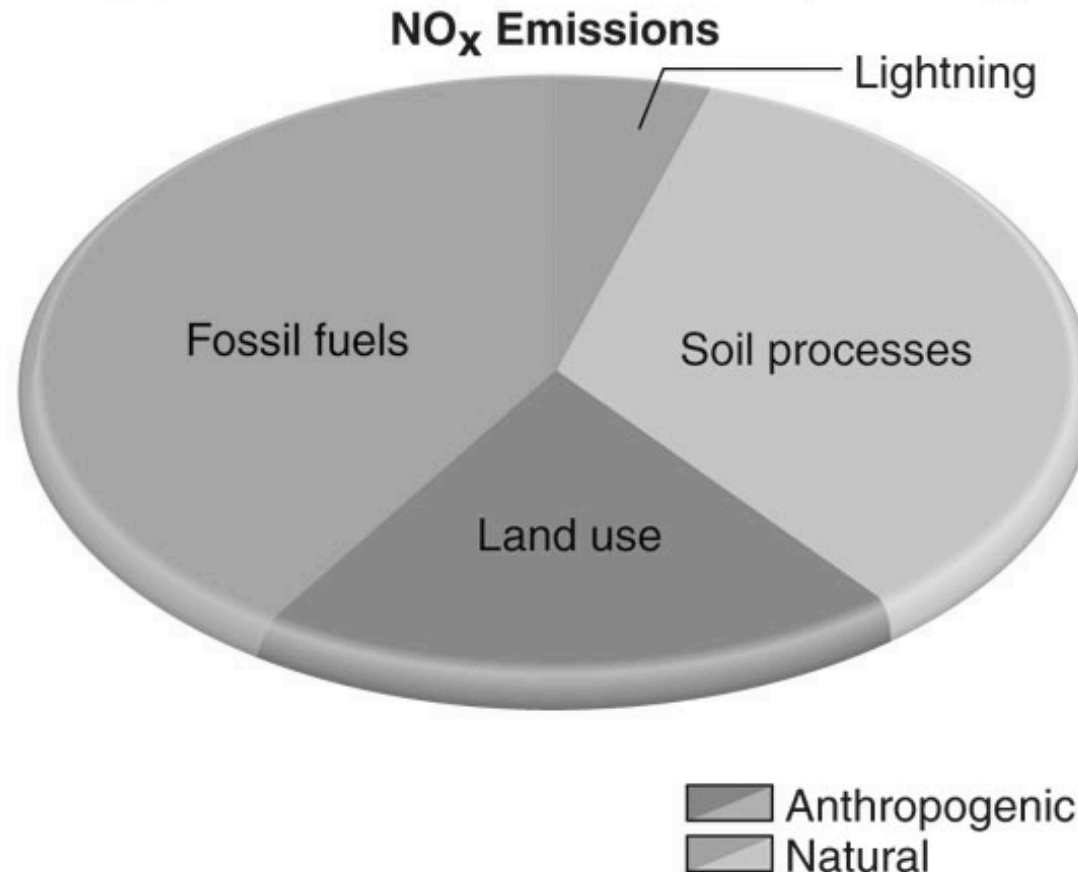
Conventional Pollutants

- Nitrogen Compounds
 - ❖ Nitrogen oxides are reactive gases formed when nitrogen is heated above 650°C in the presence of oxygen, or when nitrogen compounds are oxidized by bacteria.
 - Nitric oxide is further oxidized to give nitrogen dioxide, the reddish brown gas in smog.
 - Nitrogen oxides combine with water to make the nitric acid found in acid rain (along with sulfuric acid discussed earlier).

Nitrogen Compounds

- Excess nitrogen is causing fertilization and eutrophication of inland waters and coastal seas. It also encourages the growth of weeds that crowd out native species. Humans are responsible for 60% of emissions.

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Conventional Pollutants

- Carbon Oxides
 - ❖ Predominant form of carbon in the air is carbon dioxide.
 - Increasing levels due to use of fossil fuels
 - Cause of global warming
 - ❖ Carbon monoxide is a colorless, odorless, toxic gas produced by incomplete fuel combustion.
 - Largest proportion produced by cars/trucks
 - Inhibits respiration by binding irreversibly to hemoglobin in the blood

Conventional Pollutants

- Particulate Matter
 - ❖ Aerosol
 - solid particles or liquid droplets suspended in a gaseous medium
 - atmospheric aerosols are usually called particulate material
 - includes ash, soot, lint, smoke, pollen, spores, etc.
 - ❖ Aerosols reduce visibility.
 - ❖ When smaller than 2.5 micrometers, they enter lungs and cause damage.
 - Asbestos and cigarette smoke cause cancer.

Conventional Pollutants-Particulate Matter

- Soil erosion causes dust and sand storms that put particulate matter into air.
 - ❖ Dust can travel thousands of km. Dust from the Sahara regularly ends up in Miami, Florida. And dust from China's Gobi desert ends up in Seattle.
 - Some benefits to this movement of particulate matter as nutrients from Africa fertilize the Amazon basin

Dust Storm

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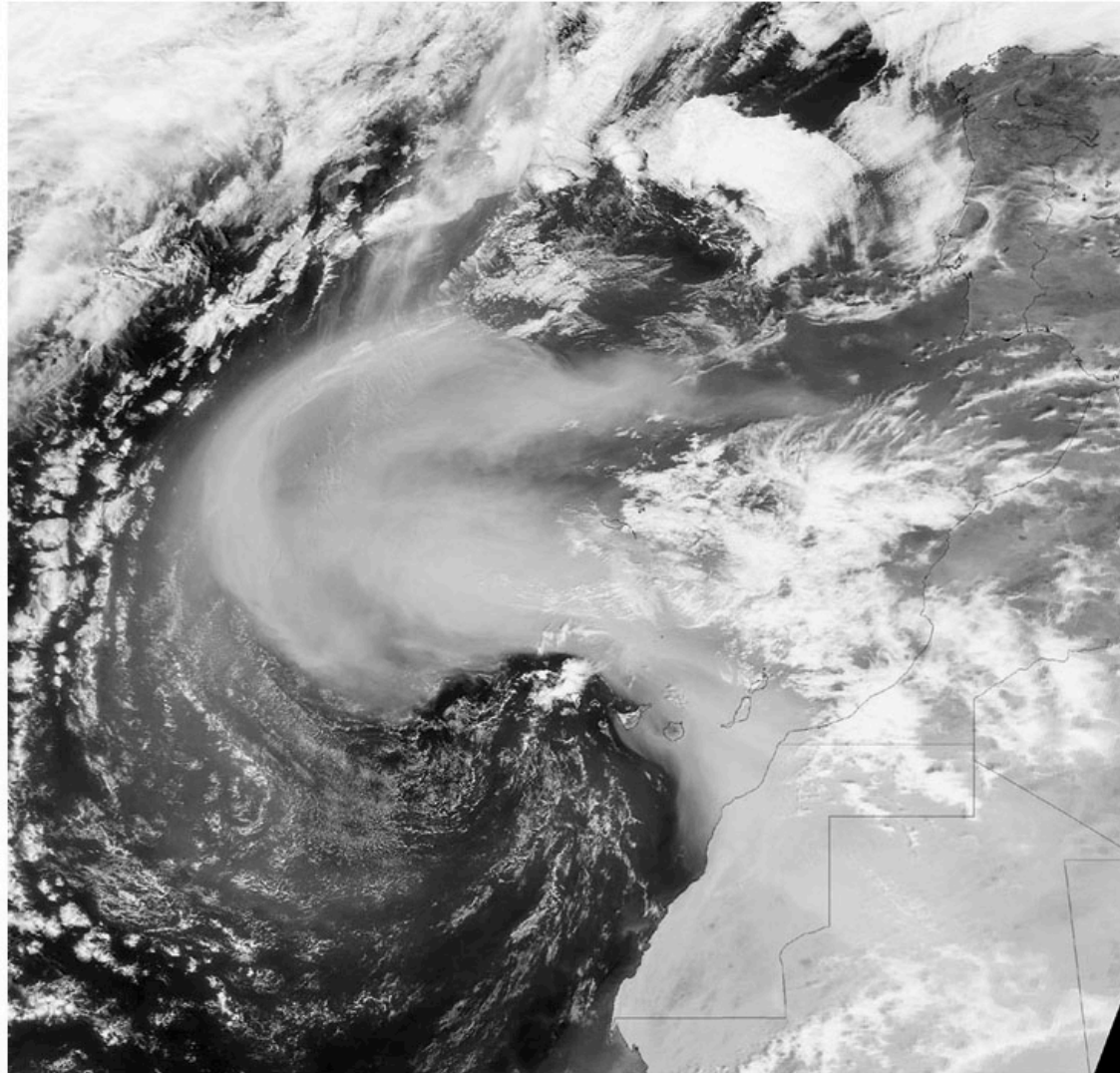


Image courtesy of Norman Kuring, SeaWiFS Project

Conventional Pollutants-Particulate Matter

- Human health suffers from exposure
 - ❖ Cities with high particulates have a higher death rate
 - ❖ Dust also carries bacteria, viruses, fungi, pesticides, herbicides and heavy metals
 - Outbreak of foot- and- mouth disease in Britain linked to dust from North Africa
 - Recent discovery of nanobacteria in dust
 - ❖ Primary source of allergies and asthma

Conventional Pollutants

- Metals
 - ❖ Many toxic metals occur as trace elements in fuel, especially coal
 - Lead- 2/3 of all metallic air pollution
 - Lead is a neurotoxin; banning lead from gas was one of most successful pollution controls in American history.
 - Since ban, children's average blood levels have dropped and average IQ has risen

Conventional Pollutants-Metals

❖ Mercury

- Dangerous neurotoxin
- Minamata, Japan disaster
- In 2007, all sampled rivers in 12 western states were contaminated
- 45 states have warnings about local fish and pregnant women and children should limit consumption of tuna, swordfish, marlin, lobster
- 300,000 to 600,000 children in U.S. exposed in the womb each year, resulting in diminished intelligence

Conventional Pollutants

- Other toxic metals
 - ❖ Nickel, beryllium, cadmium, arsenic...
- Halogens (Fluorine, Chlorine, Bromine)
 - ❖ CFCs (chlorofluorocarbons) release chlorine and fluorine in the stratosphere, which deplete ozone layer.
 - Ozone layer protects life against UV radiation
 - CFCs banned in developed countries but still used elsewhere in propellants and refrigerators

Conventional Pollutants

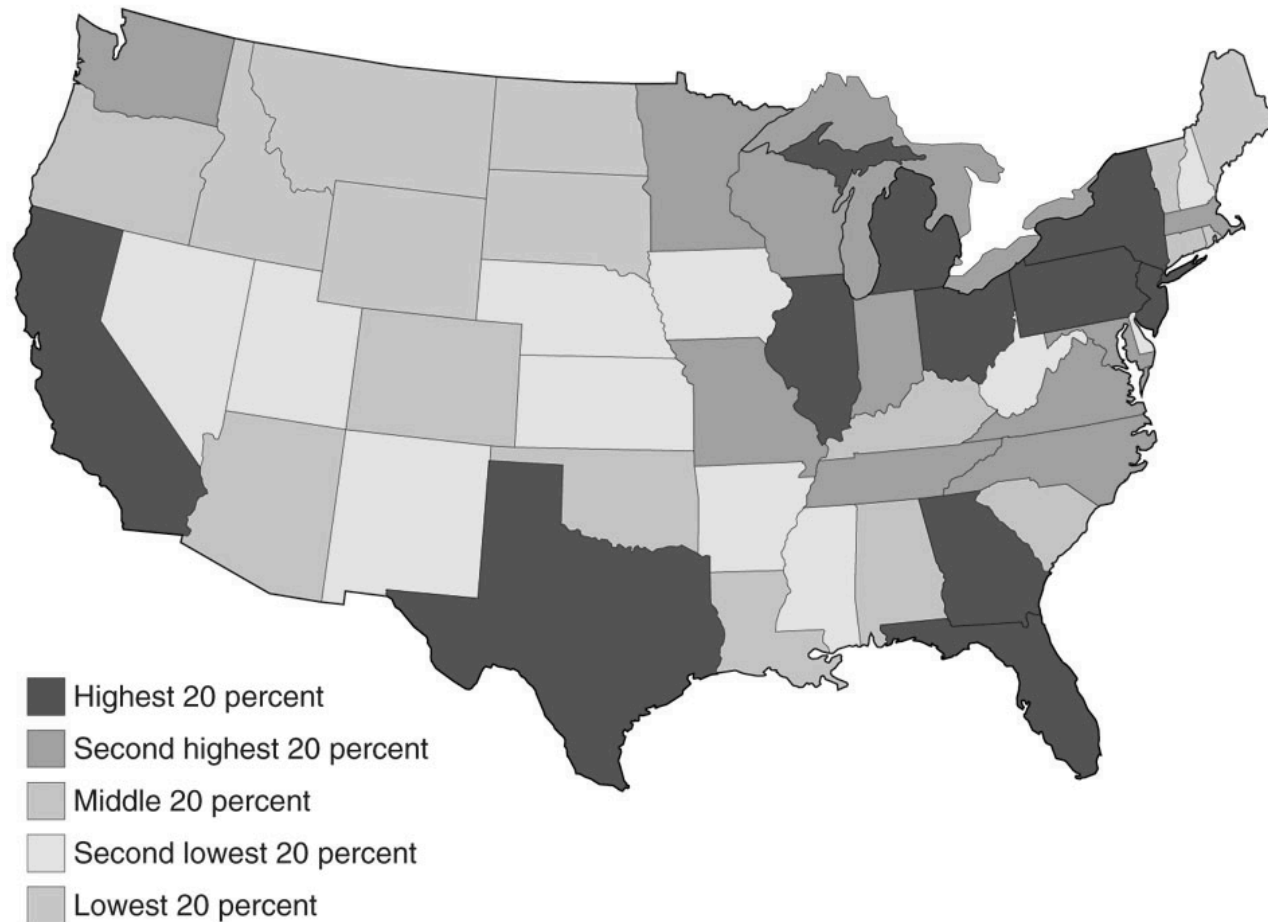
- Volatile Organic Compounds
 - ❖ Organic chemicals
 - Generally oxidized to CO and CO₂
 - Plants are largest source.
- Photochemical Oxidants
 - ❖ Products of secondary atmospheric reactions driven by solar energy.
 - Ozone formed. In stratosphere, it protects against UV radiation, but in ambient air it contributes to smog and damages lungs.

Air Toxins

- Hazardous Air Pollutants
 - ❖ Require special reporting and management as they remain in ecosystems for a long period of time, and tend to accumulate in animal tissues.
 - Include carcinogens, neurotoxins, endocrine disrupters
 - ❖ Toxic Release Inventory
 - Requires manufacturers to report on toxin release and waste management
 - ❖ Most HAP are decreasing but mercury and dioxins (from plastics) are increasing

More than 100 million Americans live in areas where cancer rate is 10X normal standard.

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Unconventional Pollutants

- Aesthetic Degradation
 - ❖ Noise, odor, light pollution
 - Reduce quality of life.
 - Light pollution prevents us from seeing stars and is a serious problem for astronomers.

Indoor Air Pollution

- EPA found indoor concentrations of toxic air pollutants are often higher than outdoor.
 - ❖ People generally spend more time indoors.
 - ❖ Smoking is the most important air pollutant in the U.S.
 - 400,000 die annually from diseases related to smoking. This is 20% of all mortality.
 - Associated costs are estimated at \$100 billion annually.
 - ❖ Chloroform, benzene and other chemicals can be found in homes at concentrations that would be illegal in workplace.

Indoor Air Pollution

- Less Developed Countries also suffer from indoor air pollution.
 - ❖ Organic fuels make up majority of household energy.
 - Often burned in smoky, poorly ventilated heating and cooking fires.

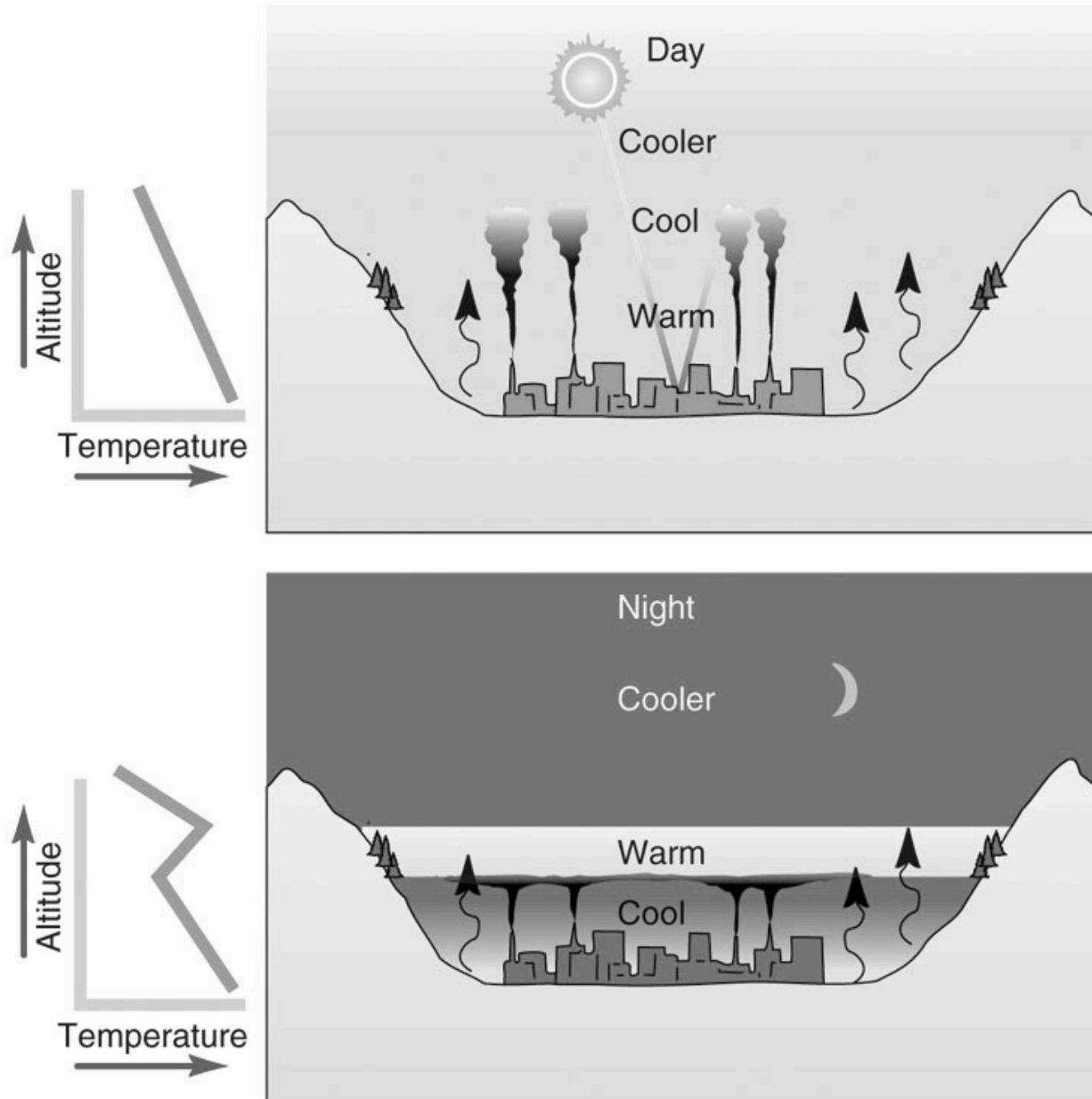
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Climate and Topography

- Inversions
 - ❖ Temperature inversions occur when a stable layer of warm air overlays cooler air, reversing the normal temperature decline with increasing height, and preventing convection currents from dispersing pollutants.
 - Cold front slides under warm air mass.
 - Cool air subsides down slope.
 - Rapid nighttime cooling in a basin



Dust Domes and Heat Islands

- Sparse vegetation and large amounts of concrete and glass create warm, stable air masses, heat islands, over large cities.
 - ❖ Concentrates pollutants in a “dust dome”.
 - Rural areas downwind from major industrial areas often have significantly decreased visibility and increased rainfall.

Long-Range Transport

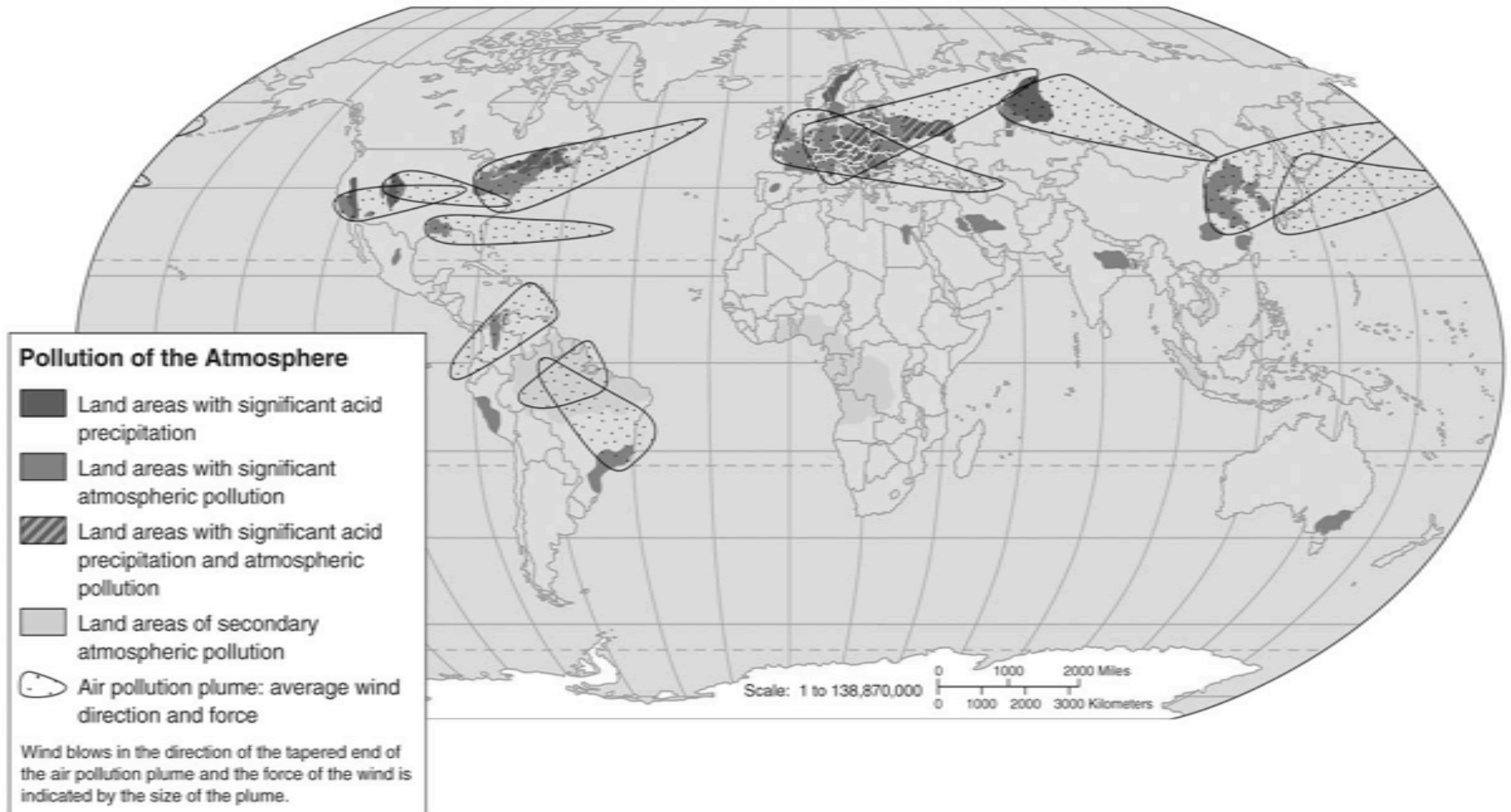
- Fine aerosols can be carried great distances by the wind.
 - ❖ 3 km toxic cloud covers India for most of year, causing 2 million deaths/yr.
 - Cloud may also be disrupting monsoon rains on which harvests in South Asia depend
 - When cloud drifts over Indian Ocean at end of monsoon season, it may be changing El Nino patterns

Long-Range Transport

- Increasingly, sensitive monitoring equipment has begun to reveal industrial contaminants in places usually considered among the cleanest in the world (e.g. Antarctica).
 - ❖ Grasshopper transport - volatile compounds evaporate from warm areas; travel to poles where they condense and precipitate. Contaminants bioaccumulate in food webs. Whales, polar bears, sharks have dangerously high levels of contaminants.

Long-Range Transport

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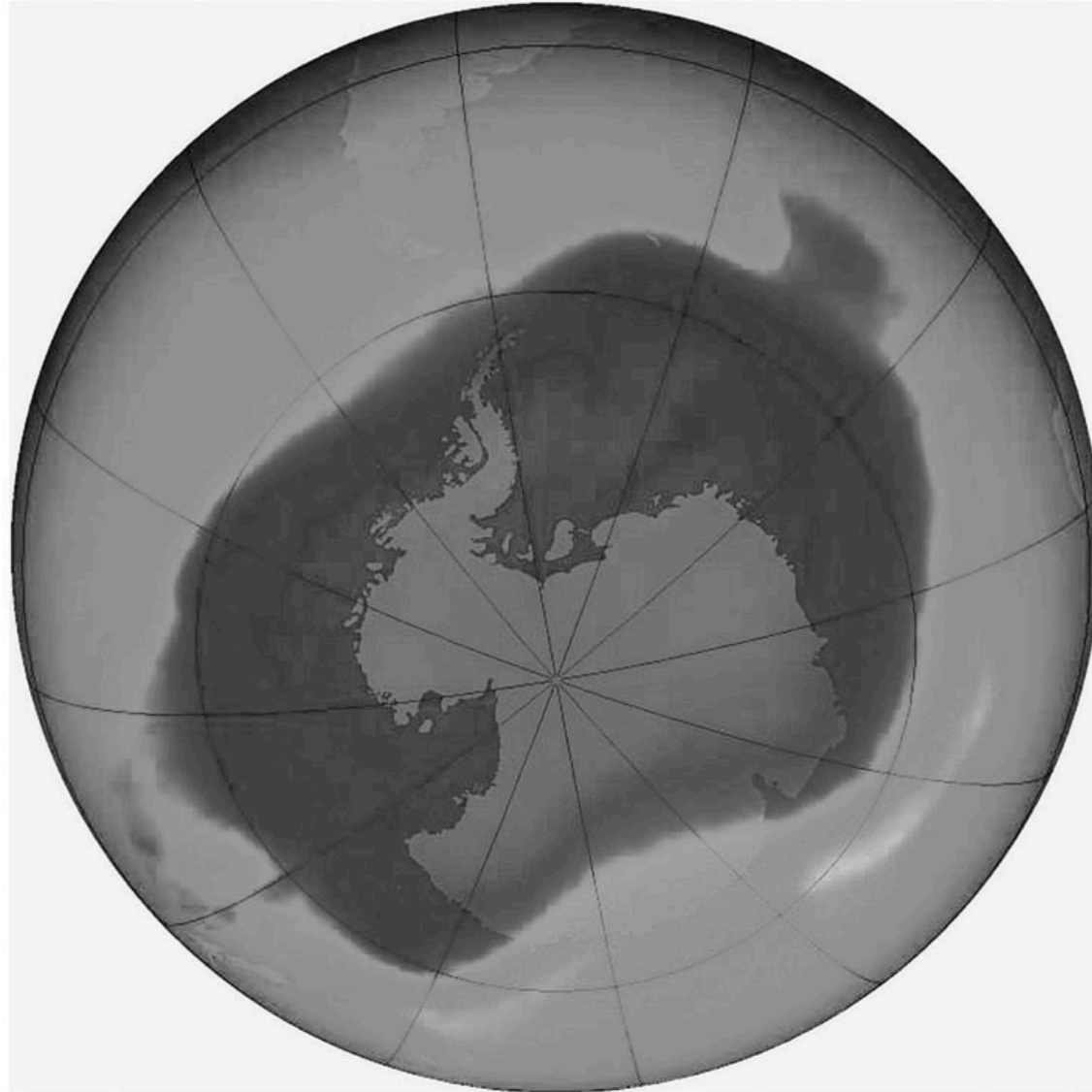


Stratospheric Ozone

- Discovered in 1985 that stratospheric ozone levels over South Pole were dropping rapidly during September and October.
 - ❖ Occurring since at least 1960
 - ❖ Chlorofluorocarbons are the cause.
- At ground-level, ozone is a pollutant, but in the stratosphere it screens UV radiation.
 - ❖ A 1% decrease in ozone could result in a million extra human skin cancers per year worldwide.
 - ❖ Decreased agricultural production and reduced plankton in the ocean, the basis of food chain

Ozone Hole Over Antarctic

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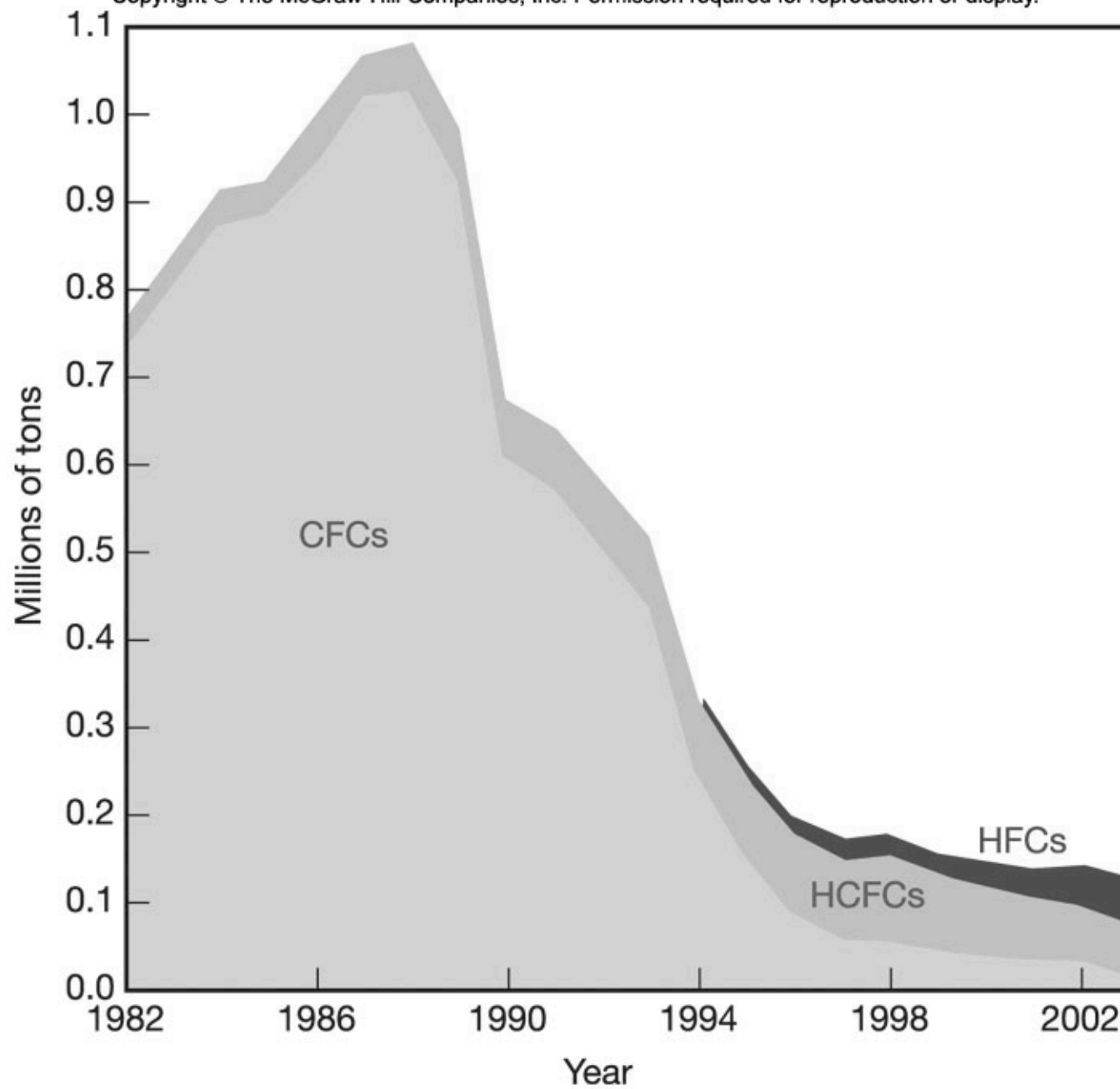


Stratospheric Ozone

- Circumpolar vortex isolates Antarctic air and allows stratospheric temperatures to drop and create ice crystals at high altitudes.
 - ❖ Absorb ozone and chlorine molecules.
 - When sun returns in the spring, energy liberates the chlorine allowing it to destroy ozone
 - Persist for decades
 - Ozone hole has grown almost every year. Now larger than North America
 - Hole has begun to form over Arctic, too

Montreal Protocol

- Montreal Protocol (1987) phased out use of CFCs. HCFCs were substituted, which release less chlorine.
- Very successful - CFCs cut by 95%
- In 1995, Rowland, Molina and Crutzen shared Nobel Prize for work on ozone problem.



Effects of Air Pollution

- Human Health
 - ❖ WHO estimates each year 5-6 million people die prematurely from illnesses related to air pollution.
 - Likelihood of suffering ill health is related to intensity and duration of exposure.
 - As much as a 5 to 10 year decrease in life expectancy if you live in worst parts of Los Angeles

Effects of Air Pollution

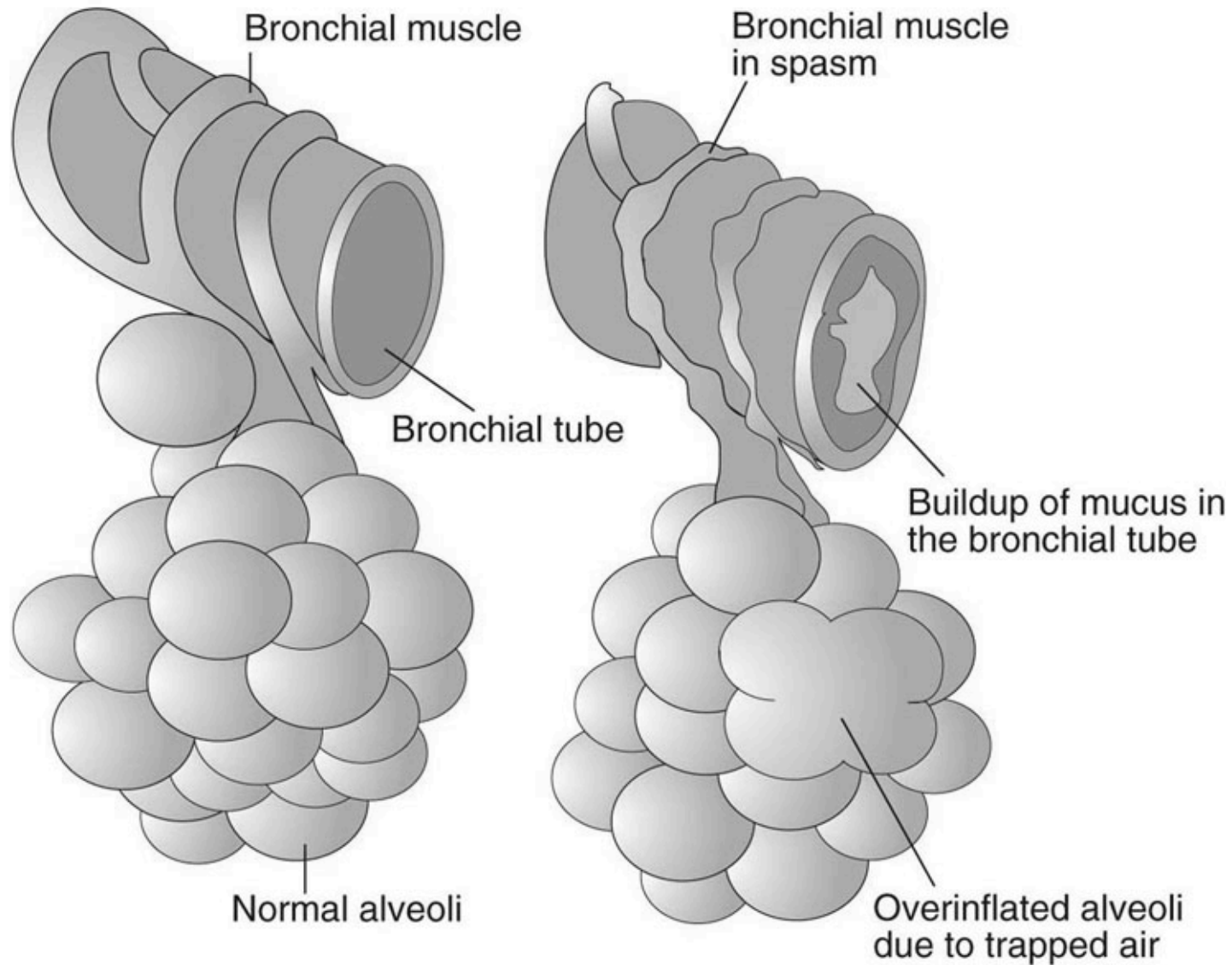
- PM2.5 - particulates less than 2.5 micron in diameter are particularly risky and have been linked with heart attack, asthma, lung cancer and abnormal fetal development.
- New rules will remove particulates from diesel engines and power plants.
- Most air pollutants are inhaled, but some can be directly absorbed through the skin or ingested in food and water.

Human Health

- Bronchitis
 - ❖ Persistent inflammation of airways in the lung that causes mucus build-up and muscle spasms constricting airways.
 - Can lead to emphysema - irreversible chronic obstructive lung disease in which airways become permanently constricted and alveoli are damaged or destroyed.
 - In the U.S. half of all lungs examined at autopsy show alveolar deterioration.

Normal vs. Constricted Airways

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Plants are Susceptible to Pollution

- Chemical pollutants can directly damage plants or can cause indirect damage by reducing yields.
 - ❖ Certain environmental factors have synergistic effects in which the injury caused by the combination is more than the sum of the individual exposures.
 - Pollutant levels too low to cause visible effects may still be damaging.

Soybean Leaves Damaged by Sulfur Dioxide

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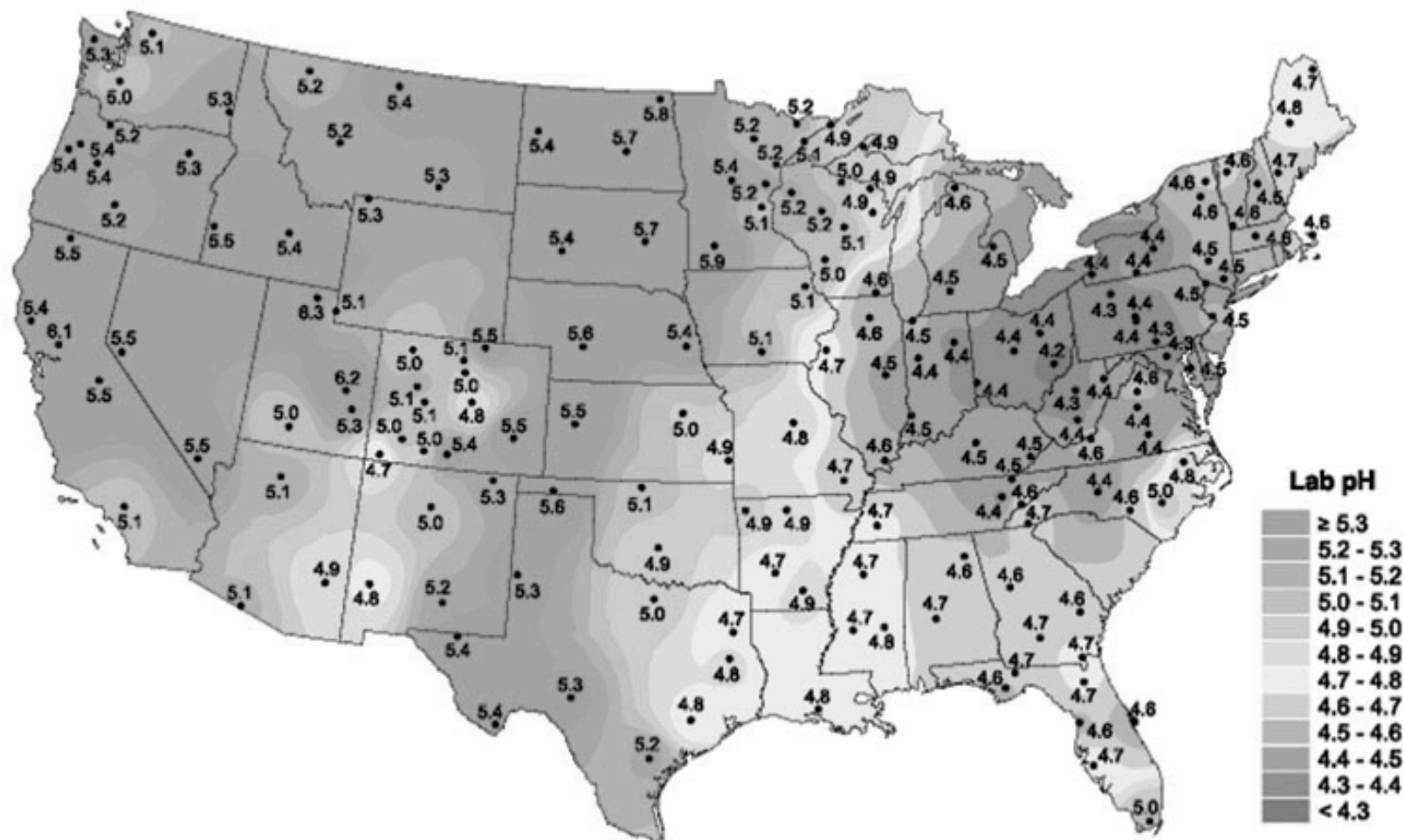
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Acid Deposition

- Acid precipitation - deposition of wet acidic solutions or dry acidic particles from the air
 - ❖ Unpolluted rain generally has pH of 5.6.
 - Carbonic acid from atmospheric CO_2
 - ❖ H_2SO_4 and HNO_3 from industrial and automobile emissions are cause of acid precipitation.
 - ❖ Aquatic effects are severe, as pH of 5 in freshwater lakes disrupts animal reproduction and kills plants, insects and invertebrates. Below pH 5, adult fish die.

Acid Precipitation

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Acid Deposition

- Forest Damage
 - ❖ Air pollution and depositions of atmospheric acids are believed to be important causes of catastrophic forest destruction in Europe, North America.
- Buildings and Monuments
 - ❖ Limestone and marble are destroyed by air pollution at an alarming rate.
 - ❖ Corroding steel in reinforced concrete weakens buildings, roads, and bridges.
- Smog and Haze reduce visibility.

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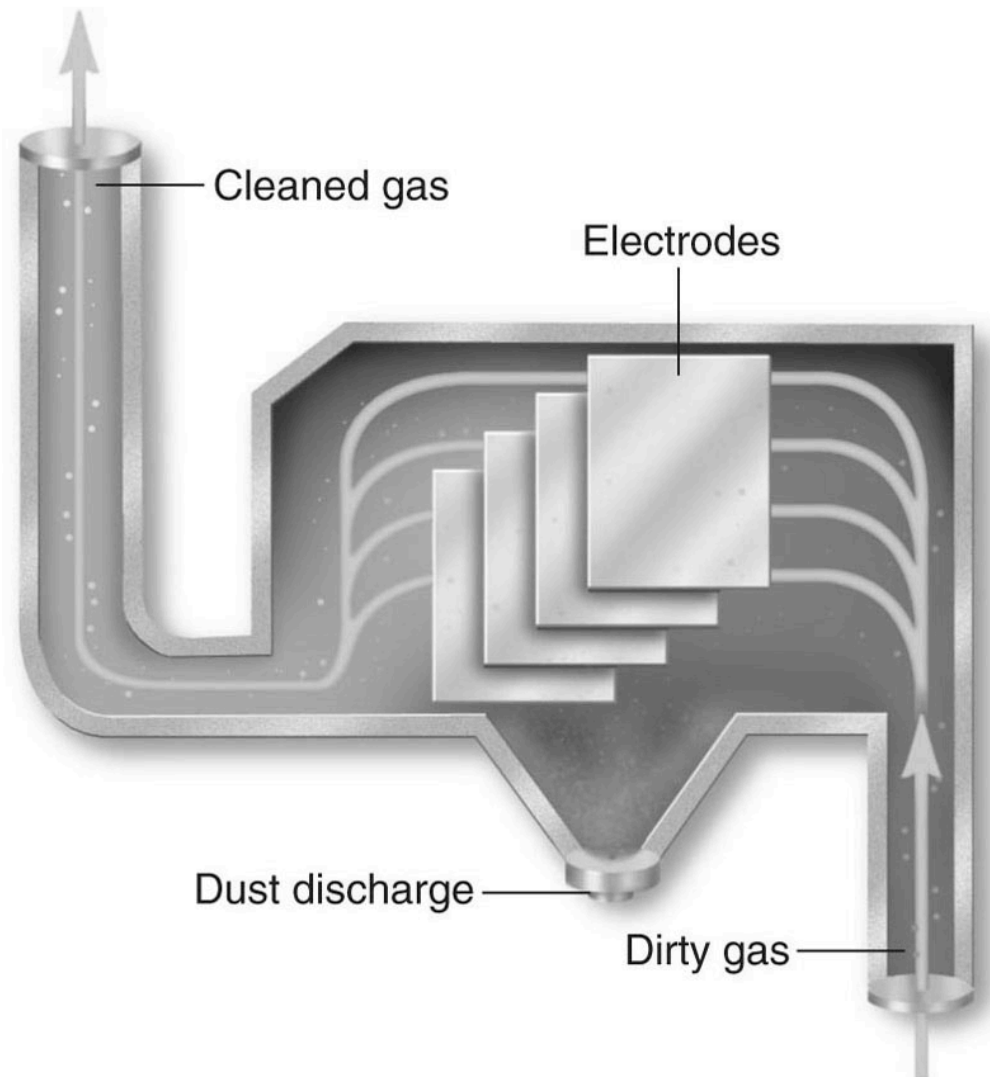
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Air Pollution Control

- Reducing Production
 - ❖ Particulate Removal
 - Remove particles physically by trapping them in a porous mesh which allows air to pass through but holds back solids.
 - Electrostatic Precipitators - fly ash particles pick up electrostatic charge as they pass between large electrodes in waste stream, and accumulate on collecting plate

Electrostatic Precipitator

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Air Pollution Control

❖ Sulfur Removal

- Switch from soft coal with a high sulfur content to low sulfur coal.
- Change to another fuel (natural gas).

❖ Nitrogen Oxides

- Best method is to prevent creation
 - Staged Burners
 - Selective Catalysts

❖ Hydrocarbon Control

- Use closed systems to prevent escape of fugitive emissions.

Clean Air Legislation

- Clean Air Act (1963) - First national air pollution control
- Clean Air Act (1970) rewrote original.
 - ❖ Identified critical pollutants.
 - ❖ Established ambient air quality standards.
 - Primary Standards - human health
 - Secondary Standards - materials, crops, visibility, climate and comfort

Clean Air Legislation

- ❖ Source review in 1977 allowed old plants to be grandfathered in, but required new equipment to meet air pollution standards.
 - Result was that companies kept old facilities operating in order to avoid pollution controls
 - Thirty years later, these old plants (often expanded in size) continue to be among biggest contributors to smog/acid rain.
 - Clinton attempted to force utilities to install new equipment; Bush abandoned this in favor of voluntary controls and air pollution allowances.

Cap and Trade

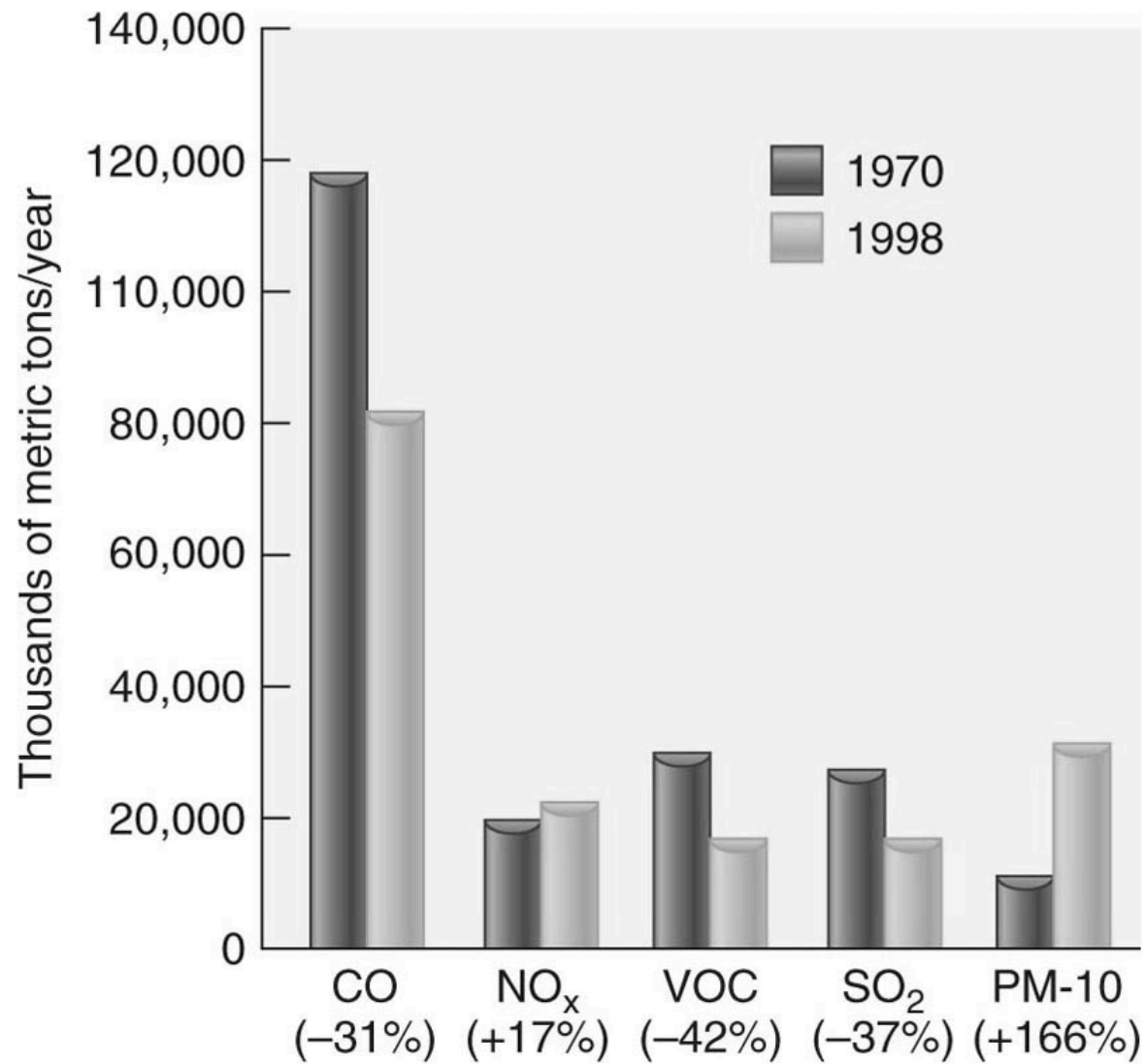
- Cap and Trade programs set maximum amounts for pollutants, but let facilities facing costly cleanups pay others with lower costs to reduce emissions on their behalf.
 - ❖ Has worked well for sulfur dioxide
 - ❖ However, it permits local hot spots where high polluters continue to pollute because they are paying someone somewhere else to reduce pollution.

Current Conditions and Future Prospects

- Air pollution in the US has improved dramatically in the last decade.
- For the 23 largest cities in the US, the number of days per year with hazardous levels of pollutants has declined 93%.
- Lead, sulfur dioxide, carbon monoxide, and ozone have all declined significantly.
- The only pollutants that have not shown significant declines are particulates and Nitrogen Oxides.
- 80% of U.S. cities now meet National Ambient Air Quality Standards.

Air Pollution Trends in the U.S.

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Source: Environmental Protection Agency, 2002.

Air Pollution in Developing Countries

- ❖ Mexico City
 - Pollution levels exceed WHO health standards 350 days per year.
 - More than half of children have lead levels high enough to lower intelligence.
- ❖ China's 400,000 factories have no air pollution controls.
- ❖ Former Soviet Union has serious problems as well.

Signs of Hope

- Sweden and West Germany cut their sulfur emission by two-thirds between 1970 and 1985.
- Australia and Switzerland even regulate motorcycle emissions.
- Delhi, India was once one of world's most polluted cities. Breathing the air equal to smoking 2 packs a day. After instituting air pollution controls, air is dramatically cleaner.